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Earthquake Predictability & Retrospective Earthquake Prediction Tests

Andrew Michael, USGS
NEPEC meeting, May 4, 2006

- Summary of the 1999 *Nature* online debate on Earthquake Prediction
- Retrospective earthquake prediction testing:
  - a necessary evil
  - issues for good retrospective tests
  - what NEPEC should do

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The 1999 Online Nature Bebate on Earthquake Prediction

• An experiment in using "the space and reach of the Web to map out and define the landscape of international scientific controversy."

  • 5 debates from 1998 to 2001

•Moderated by Ian Main

•Invited Participants: Bob Geller, Max Wyss, Pascal Bernard, Andy Michael, Chris Scholz, Leon Knopoff, David Jackson

•Email contributions: Per Bak, David Bowan & Charlie Sammis, Francesco Biagi, Stuart Crampin, Zhongliang Wu, Didier Sornette

•26 total contributions over 7 weeks

Ian Sets up the Debate

Four levels of predictability:

Consensus

1. Time-independent hazard — Yes
2. Time-dependent hazard
    1. an earthquake cycle — No consensus
    2. clustering — Yes and being used in California
3. Intermediate to short term forecasting — No consensus on possibility but not possible in near future
4. Deterministic prediction such that a planned evacuation could take place — No

Routes Forward

- Better understanding of the seismic source (consensus)
    - much discussion of criticality and SOC
    - do events recur, are gaps useful (Jackson and Scholz)
- Understanding and observing transient behavior - PBO like ideas (Bernard)
- Improved testing of hypotheses through known benchmarks: better than clustering
- Improved quality of research

Geller on better research:

1. No special funding for prediction resarch.
2. Avoid case studies
3. Journals should reject poor work
4. Avoid prediction oriented communities or even special sessions
5. Question the existence of special counsels such as IASPEI sub-commission, NEPEC

Wyss on better research:

1. Poor funding => poor research
2. Need more funding for research
3. Prediction research shouldn't be avoided
4. Avoid case studies, but recognize their importance
5. Journals should reject poor work
6. Break down special communities with inter-disciplinary retreat meetings.

Prospective versus Retrospective Testing

Prospective Testing: rigorous but slow

Retrospective Testing: timely but dependent on design of the test

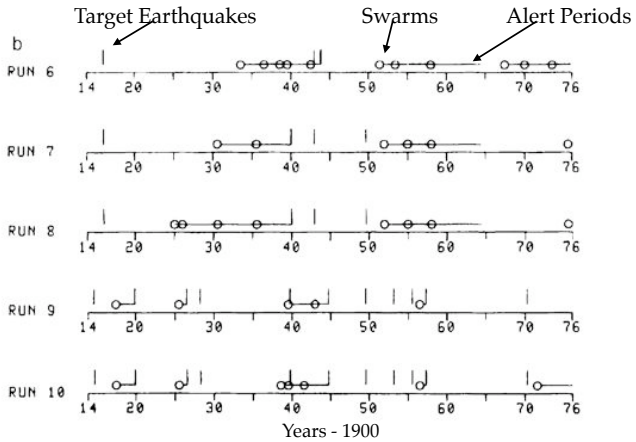
Societal attention to earthquake predictions makes timeliness important so that retrospective testing becomes a necessary evil.

Tests Must Match Hypotheses

What is the null hypothesis?

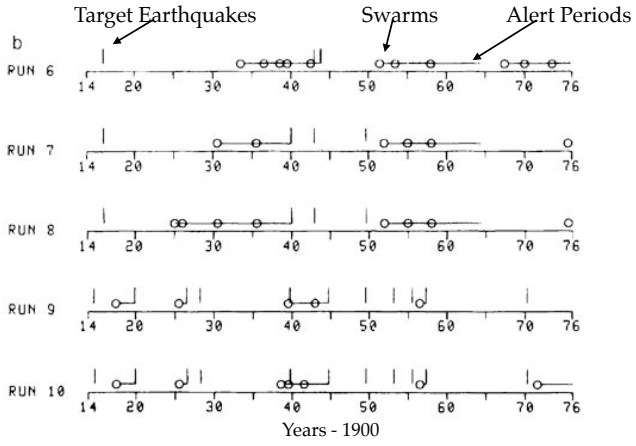
Random anomalies or seismicity patterns, or
Random target earthquakes

Example from Michael & Toksöz, 1982, test of Keilis-Borok swarm hypothesis



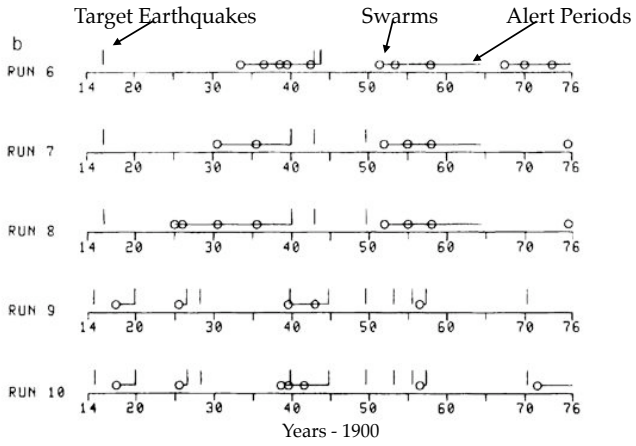
Keilis-Borok Approach

Randomize the target events
Measure time in alert periods versus time outside of alerts
Use binomial distribution, simple but incorrect due to problems
Problems: early events hard to predict, time in alerts depends on events



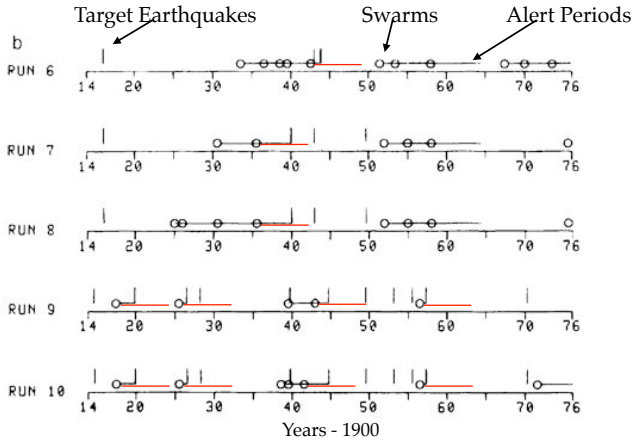
Michael & Toksöz Approach

Randomize the swarms, predictable earthquakes shouldn't be random
Compute significance with complex combinatoric approach or Monte Carlo



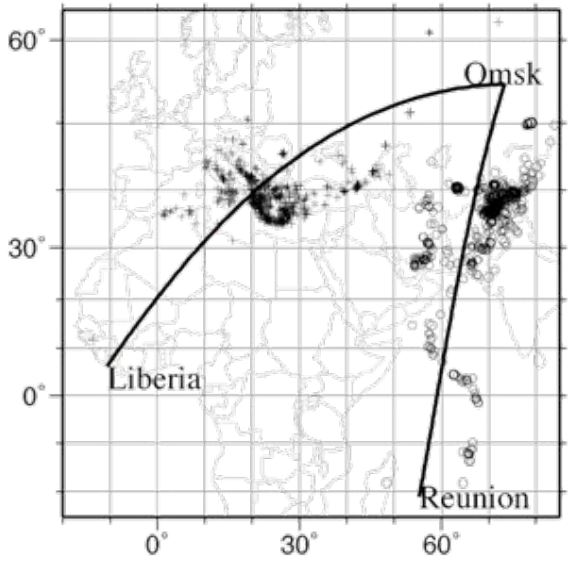
Keilis-Borok Approach Changes

Allow alert periods to continue after target events occur
Now binomial process is correct
But the hypothesis has changed
Do the swarms lead up to an event or show that the region is hazardous?



The Importance of Clustering in Prediction Tests

Example from Michael, 1996, 1997, test of VLF-based Predictions



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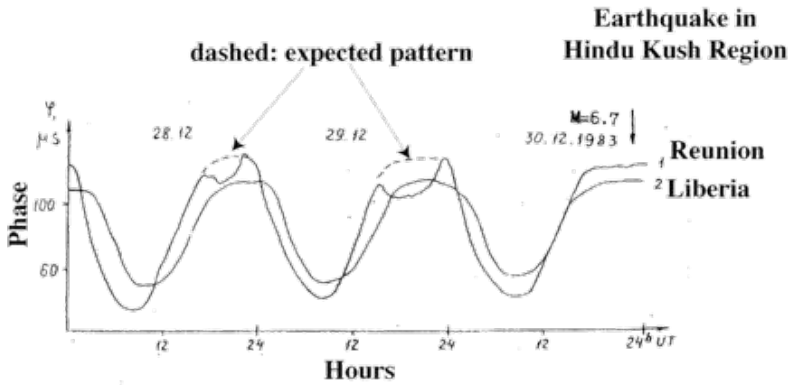
The Importance of Clustering in Prediction Tests

Phase Of Omega Signals As Received At Omsk For December 28-30, 1983



after Reutov and Marenko, 1995

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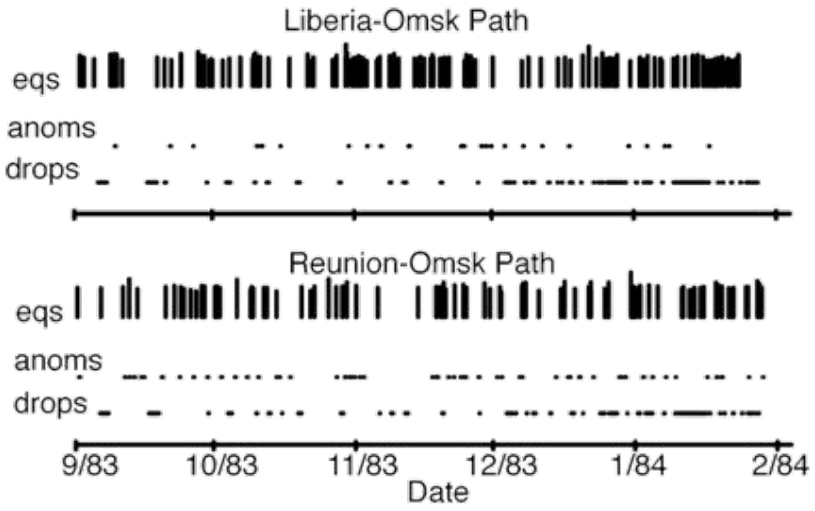

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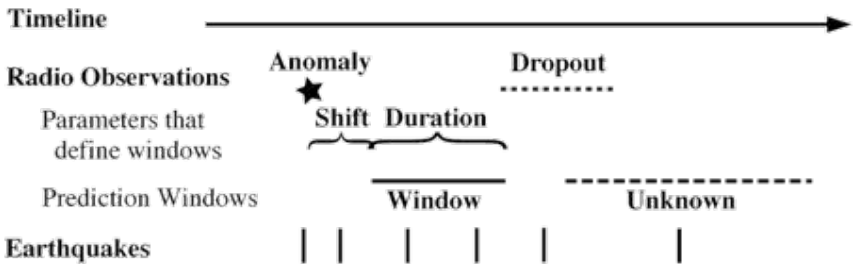
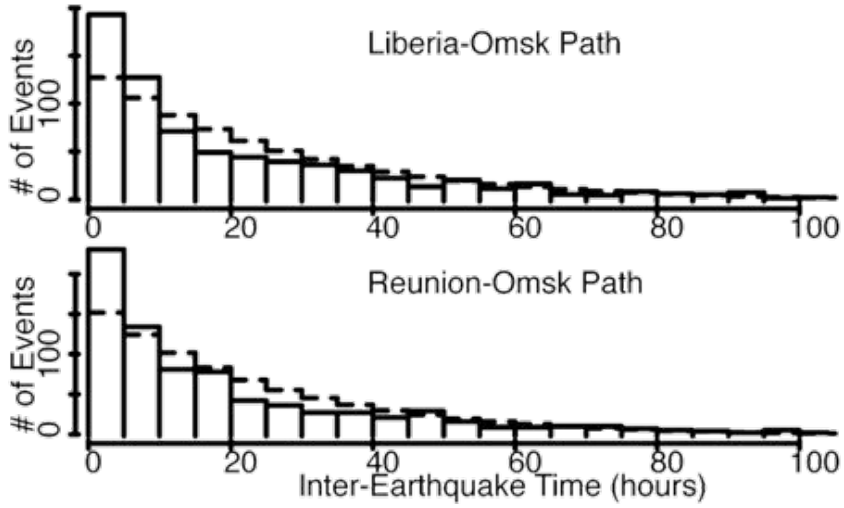


The Importance of Clustering in Prediction Tests

Randomize Earthquakes (because we don't know the statistics of the VLF anomalies)

1. Poisson or exponential inter-event times, but….



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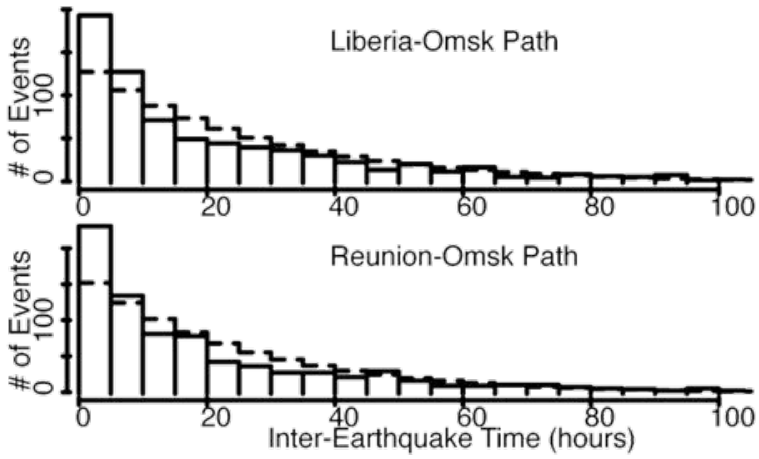
2. Empirical inter-event times



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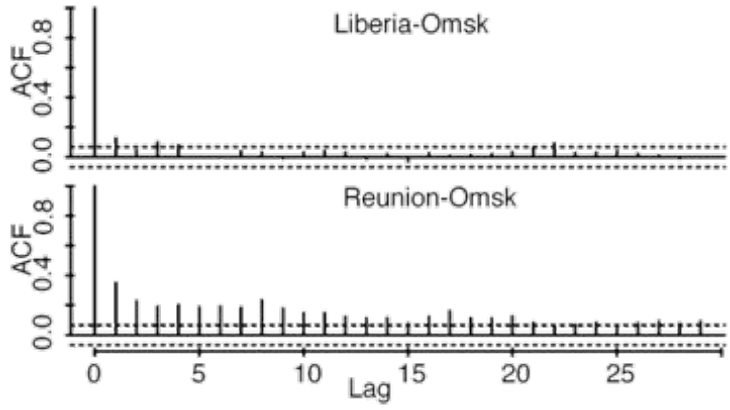
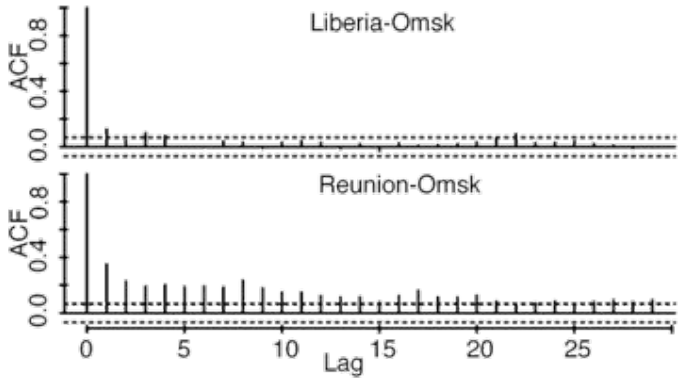


The Importance of Clustering in Prediction Tests

Randomize Earthquakes (because we don't know the statistics of the VLF anomalies)

1. Poisson
2. Empirical inter-event times
3. FOA - first-order autoregression of inter-event times



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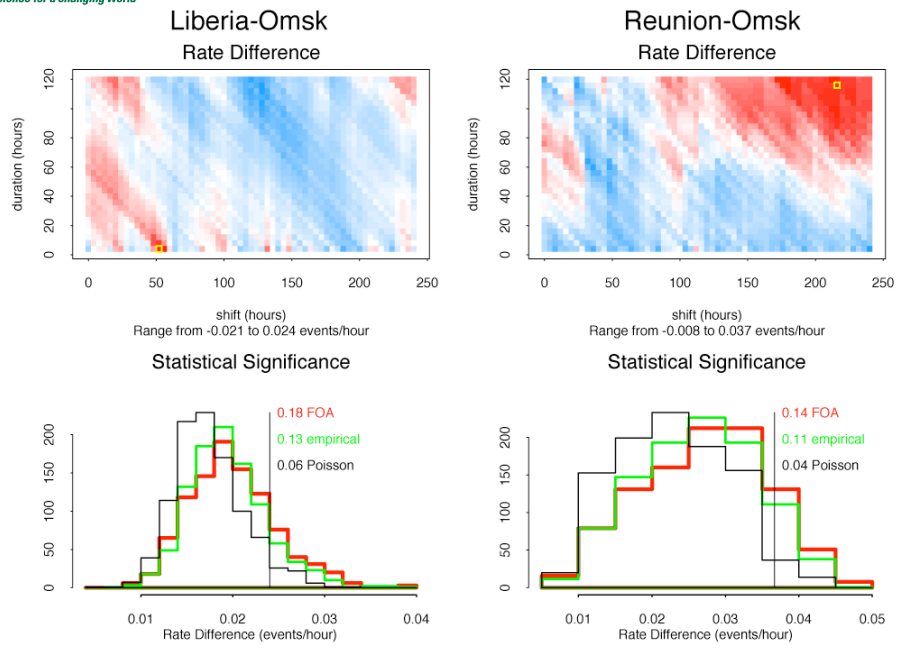


Why Does Clustering Matter?

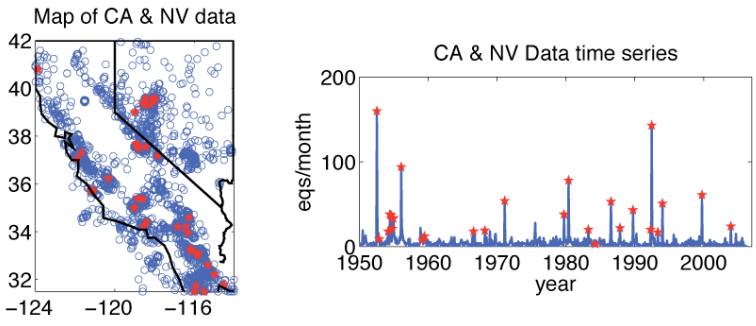
1. Optimization in prediction tests by varying parameters is a search for extreme behavior.
2. Clustering makes the behavior of this optimization by data-fitting less stable.
3. Hence more extreme behavior (a.k.a. better predictions) will be found if clustering is included.
4. Clustering exists in real earthquakes and will contribute to "better predictions."
5. A lack of clustering in simulated catalogs will lead to over-estimating statistical significance.
6. Therefore clustering must be included in simulated earthquake catalogs or the simulated catalogs won't lead to valid statistical tests.

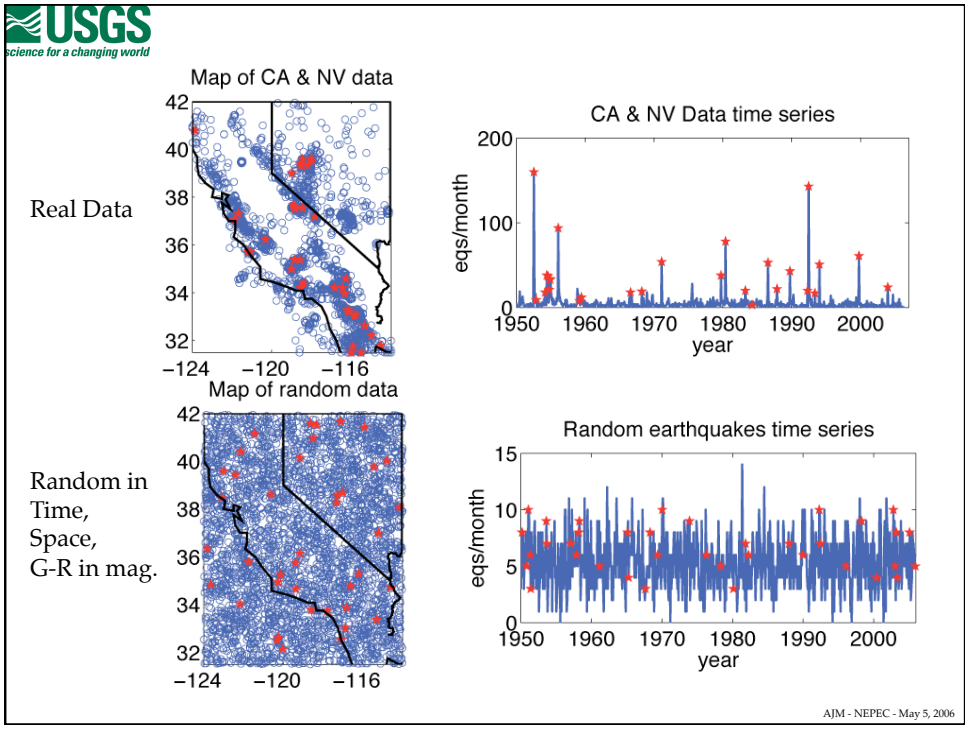
Simulating Seismicity in Space and Time

For the VLF study, seismicity was simulated only in time.
For many studies, e.g. AMR or time-to-failure, we need to simulate the seismicity in both time and space.

Three simulation methods from ongoing work by Felzer, Hardebeck, and Michael

Actual data, 1950 to 2006, M≥4, Stars are M≥6

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Real Data
Map of CA & NV data
CA & NV Data time series
eqs/month
year
Random in Time, Space, G-R in mag.
Map of random data
Random earthquakes time series
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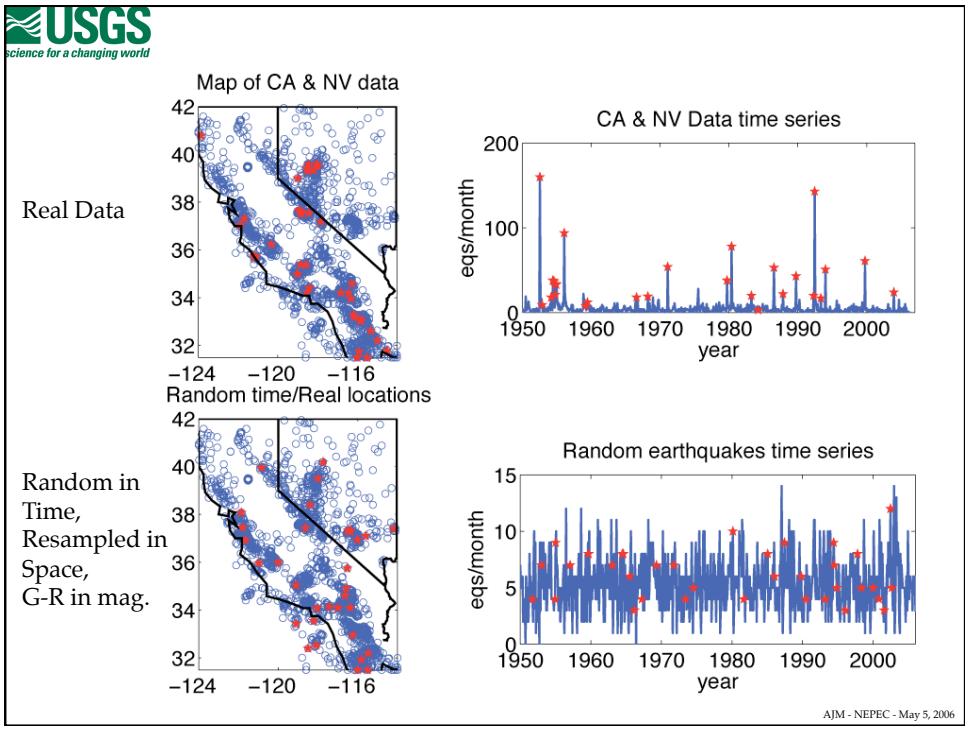
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Real Data
Map of CA & NV data
CA & NV Data time series
eqs/month
year
Random time/Real locations
Random in Time, Resampled in Space, G-R in mag.
Random earthquakes time series
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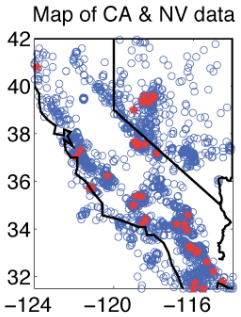
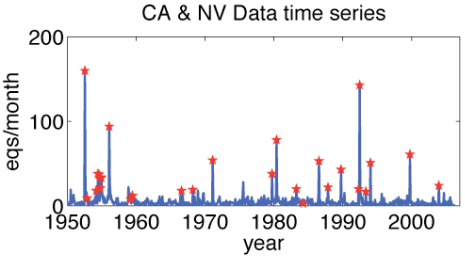
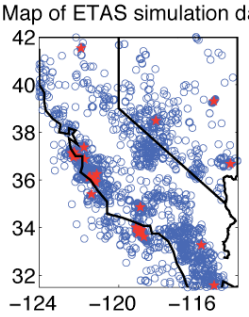
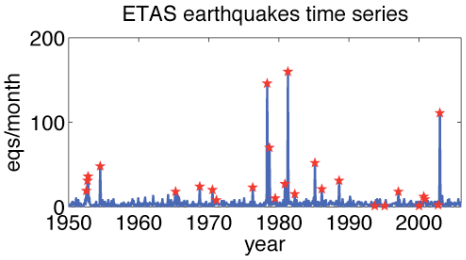
Real Data





Spatially varying background rates based on real data, plus ETAS, G-R in mag.





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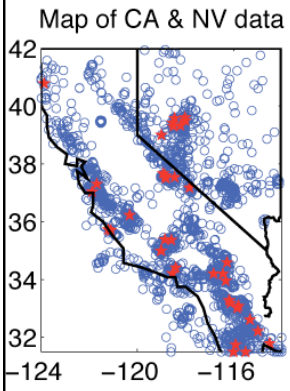
Estimating Rate of Independent Background Events

Real Data



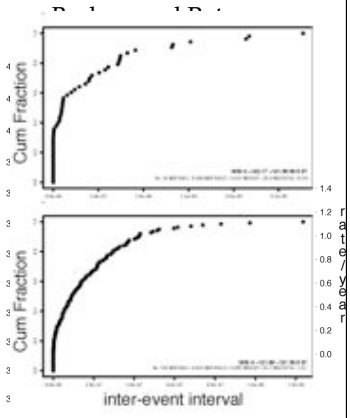
In each 0.5° bin:

Compute inter-event times

Fit to Gamma distribution

Estimate fraction of events independent using Hainzl et al. (BSSA, 2006)

Estimate rate from number of events, time period, and fraction that are independent.



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Getting Ready for Future Prediction Tests

1. What sort of predictions are useful? Set guidelines of what you might and might not be interested in.
2. What are reasonable null hypotheses?
3. Many prediction tests will require synthetic seismicity catalogs so setting standards for the production of multiple synthetic seismicity catalogs for NEPEC related tests would help speed work when a prediction is proposed.
4. Testing using synthetic catalogs and varying parameters, or learning and testing subsets.